

## CLAIMS

1. Apparatus for measuring a surface geometry of hard tissue covered by a layer of soft tissue, comprising:
  - 5 (a) a plurality of elements each having a tip adapted to penetrate said soft tissue and not substantially penetrate said hard tissue;
  - (b) a frame supporting movement of said elements, each along a path, such that a plurality of said tips, when positioned along the paths, define a surface; and
  - (c) at least one position sensor which generates a signal indicative of a tip position of at  
10 least one of said elements.
2. Apparatus according to claim 1, wherein said path comprises a path along an axis of said elements.
- 15 3. Apparatus according to claim 1, wherein said elements are elongate.
4. Apparatus according to claim 1, wherein said frame comprises two substantially oppositely facing panels, each of which panels supports a plurality of said elements.
- 20 5. Apparatus according to claim 4, wherein said frame comprises at least one upper panel supporting a plurality of said elements.
6. Apparatus according to claim 4, wherein said frame comprises at least one upper panel supporting at least one fixed soft tissue penetration element.  
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7. Apparatus according to claim 4, wherein said tips are adapted to measure at least three sides of a shape generally corresponding to a rectangle, while mounted in said frame.
8. Apparatus according to claim 4, wherein said elements are arranged as a first set  
30 perpendicular to one plane, a second set generally facing said first plane and a third set oblique to said first and second sets.

9. Apparatus according to claim 1, wherein at least some of said plurality of elements are arranged in two dimensions, with at least three elements in each of two orthogonal directions.

10. Apparatus according to claim 1, wherein said frame is adapted for disassembly.

11. Apparatus according to claim 1, wherein said plurality of elements comprises at least 10 elements.

12. Apparatus according to claim 1, wherein said plurality of elements comprises at least 30 elements.

13. Apparatus according to claim 1, sized and having a geometry adapted for a dental application of measuring a surface of a jaw bone based on axial positions of said tips.

14. Apparatus according to claim 1, wherein said hard tissue comprises cortical bone tissue.

15. Apparatus according to claim 1, wherein said tips have a density of at least one tip per nine square millimeters.

16. Apparatus according to claim 1, wherein said tips have a density of at least one tip per square millimeter.

17. Apparatus according to claim 1, wherein said frame substantially allows only motion of each of said elements, along an axis of the element.

18. Apparatus according to claim 17, wherein said frame is limited to non-axial motion to within a tolerance of less than 10% of a pitch of said elements.

19. Apparatus according to claim 18, wherein said frame allows only axial motion of said elements, within a tolerance of less than 5% of a pitch of said elements to non-axial motion of said tips.

20. Apparatus according to claim 1, wherein said tips are made sharp enough to penetrate soft tissue but not so sharp that they penetrate cortical bone under an application force of under 50 grams.
- 5 21. Apparatus according to claim 1, wherein said tips include a bone stop which prevents entry of the elements into bone tissue past said a predetermined distance.
22. Apparatus according to claim 1, wherein said at least one encoder comprises a single encoder common to multiple elements.
- 10 23. Apparatus according to claim 22, wherein said at least one encoder comprises an imaging encoder.
24. Apparatus according to claim 1, wherein said at least one encoder comprises at least  
15 one encoder per element.
25. Apparatus according to claim 24, wherein said at least one encoder comprises an optical encoder reading a position marking off of an element.
- 20 26. Apparatus according to claim 24, wherein said at least one encoder comprises a magnetic encoder reading a position marking off of an element.
27. Apparatus according to claim 24, wherein said at least one encoder comprises a  
25 resistance encoder reading a resistance of an element.
28. Apparatus according to claim 24, wherein said at least one encoder comprises a capacitance encoder reading a capacitance of an element.
29. Apparatus according to claim 24, wherein said at least one encoder comprises a force  
30 encoder reading a compression of a spring attached to an element.
30. Apparatus according to claim 1, wherein said at least one encoder has a precision of better than 0.5 mm.

31. Apparatus according to claim 1, wherein said at least one encoder has a precision of better than 0.2 mm.
- 5 32. Apparatus according to claim 1, wherein said at least one encoder is integral to said frame.
33. Apparatus according to claim 1, wherein said at least one encoder is separate from said frame.
- 10 34. Apparatus according to claim 33, comprising a holder for at least part of said frame in which said at least one encoder is integrated.
35. Apparatus according to claim 1, comprising an element advance mechanism operative  
15 to simultaneously advance a plurality of said elements through said soft tissue at a same time.
36. Apparatus according to claim 35, wherein said element advance mechanism is adapted to apply a force limited to prevent inadvertent penetration of said hard tissue.
- 20 37. Apparatus according to claim 35, wherein said element advance mechanism comprises a pneumatic advance mechanism.
38. Apparatus according to claim 37, comprising a pneumatic channel for each of said elements.
- 25 39. Apparatus according to claim 37, wherein said advance mechanism is operable as an element retractor.
40. Apparatus according claim 1, comprising at least one position lock for at least one of  
30 said elements.
41. Apparatus according to claim 40, wherein said position lock comprises a friction lock defined by a panel perpendicular to an axial motion direction of said elements.

42. Apparatus according to claim 1, comprising a source of adhesive adapted to provide adhesive to lock said elements to said frame.

5 43. Apparatus according to claim 1, comprising at least one support adapted to lock said frame relative to at least one of said soft tissue and said hard tissue.

44. Apparatus according to claim 1, comprising a drill guide.

10 45. Apparatus according to claim 44, wherein said drill guide is adapted to guide a standard dental drill bit.

46. Apparatus according to claim 45, wherein said drill guide is adapted to limit a depth of penetration of said drill bit.

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47. Apparatus according to claim 44, wherein said drill guide is locked to said frame.

48. Apparatus according to claim 47, wherein said drill guide is adjustable in at least two degrees of freedom of position and orientation prior to being locked to said frame.

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49. Apparatus according to claim 47, wherein said drill guide is adjustable in at least three degrees of freedom of position and orientation prior to being locked to said frame.

25 50. Apparatus according to claim 48, comprising at least one encoder adapted to measure at least one of said degrees of freedom.

51. Apparatus according to claim 45, wherein said drill guide comprises at least one penetration limitation sleeve having a selectable offset from said frame.

30 52. Apparatus according to claim 51, wherein said at least one penetration limitation sleeve comprises a plurality of sleeves each having a different offset.

53. Apparatus according to claim 1, wherein said at least one encoder comprises a data output.

54. Apparatus according to claim 53, wherein said data output is wireless.

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55. Apparatus according to claim 53, comprising a three-dimensional display system to which said data output is attached, which display system is adapted to display an indication of said surface.

10 56. Apparatus according to claim 55, wherein said display system overlays said surface on a three dimensional representation of said hard tissue.

57. Apparatus according to claim 55, and including a controller configured to register said surface to said representation.

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58. Apparatus according to claim 55, wherein said display system generates alerts responsive to an undesirable spatial position of a tool relative to said surface.

15 59. Apparatus according to claim 55, wherein said display system generates an indication of at least one of a position and orientation of a drill guide mounted on said frame.

60. Apparatus according to claim 59, wherein said indication comprises indication of a projected drill bore.

25 61. Apparatus according to claim 53, comprising a computerized manufacturing system to which said data output is attached, for manufacture of a drill guide for said hard tissue.

62. Apparatus according to claim 1, comprising a plurality of elements having tips adapted to not penetrate soft tissue.

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63. A method of measuring the surface of a hard tissue underlying a soft tissue, comprising:

(a) inserting a plurality of different sharp elements through said soft tissue to a surface of said hard tissue;

(b) determining at least relative positions of tips of said sharp elements; and

5 (c) reconstructing a map of said surface of said hard tissue from said at least relative positions.

64. A method according to claim 63, comprising using said map to guide a drill to said hard tissue.

10 65. A method according to claim 64, comprising providing a drill guide for using said map.

66. A method according to claim 65, wherein said hard tissue comprises a jaw bone and wherein said soft tissue comprises hard tissue.

15 67. A method according to claim 65, comprising selecting an offset sleeve for controlling a depth of said drilling.

68. A method according to claim 65, comprising adjusting said drill guide according to said map.

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69. A method according to claim 65, wherein said elements are mounted on two opposing panels of a frame and comprising approximating said panels.

25 70. A method according to claim 65, comprising registering said map to a previously acquired radiological image of said hard tissue.

71. A method according to claim 65, comprising providing real-time feedback on at least one of a position and orientation of said drill guide.

30 72. A method according to claim 63, wherein inserting comprises inserting using a standard dental pneumatic source.

73. A method according to claim 63, comprising removing said elements using a standard dental pneumatic source.

74. A method according to claim 63, comprising removing said elements from said soft tissue prior to said determining.

75. A method according to claim 63, comprising removing said elements from said soft tissue after said determining.

76. A method according to claim 63, comprising locking said elements prior to said determining.

77. A method according to claim 63, comprising not locking said elements prior to said determining.

78. A dental surgical stent, comprising:  
(a) an active stent portion adapted to fit over a portion of a jaw bone; and  
(b) at least one visual indicator showing an activation state of said stent.

79. A dental surgical stent, comprising:  
(a) a surgical stent portion adapted for mounting on a jaw; and  
(b) a drill guide including at least one encoder which generates a signal indicative of at least one of a position and orientation of the drill guide.

80. A stent according to claim 79, wherein said surgical stent is machined for a particular jaw.

81. A stent according to claim 79, wherein said surgical stent comprises at least one mounting point for said drill guide.